DRAFT FINAL

RCRA FACILITY INVESTIGATION REPORT LANDFILL 2 (FTC-006/SWMU 2)

FORT CARSON MILITARY RESERVATION FORT CARSON, COLORADO

Prepared for

Directorate of Environmental Compliance and Management

under

U.S. Army Corps of Engineers
Omaha District
Contract No. W9128F-04-D-0001, Delivery Order 0009

June 2005

URS

8181 E. Tufts Avenue
Denver, Colorado 80237

DRAFT FINAL

RCRA FACILITY INVESTIGATION REPORT LANDFILL 2 (FTC-006/SWMU 2)

Fort Carson Military Reservation
Fort Carson, Colorado

Prepared for:

Directorate of Environmental Compliance and Management

and

United States Army Corps of Engineers
Omaha District

Contract W9128F-04-D-0001, Delivery Order 0009

Prepared By:
URS GROUP, INC.
8181 E. Tufts Avenue
Denver, Colorado 80237

June 2005

Table of Contents

Table of Contents

Table of Contents

TABLES

FIGURES

Table of Contents

APPENDICES

List of Acronyms

1,2-DCA	1,2-dichloroethane
1,2-DCP	1,2-dichloropropane
ASTM	American Society for Testing and Materials
bgs	below ground surface
COVER	Corrective Action Plan
CCR	Code of Colorado Regulations
CDPHE	Colorado Department of Public Health and Environment
CGWS	Colorado Ground Water Standards
CH	high plasticity clay
CL	low plasticity clay
CMP	Corrective Measures Plan
cm/sec	centimeters per second
COC	Chain of Custody
COD	Chemical Exygen Demand
CT	Carbon Oxygen Demand
DNAPL	dense non-aqueous phase liquid
DOT	Department of Transportation
DPW	direct-push water aample
DQCR	Daily Quality Control Report
DQO	data quality objective
Earth Tech	Earth Tech Environment and Infrastructure, Inc.
EPA	Environmental Protection Agency
ET	evapotranspiration
FD	field duplicate
FLPM	Field and Laboratory Procedures Manual
Fort Carson	Fort Carson Military Reservation
GPL	groundwater protection levels
IDW	investigative derived waste
LEL	lower explosive limit
LNAPL	light non-aqueous phase liquid
MC	methylene chloride
MCPA	2-methyl-4-chlorophenoxyacetic acid
MDL	method detection limit
MW	monitoring Well
µg/kg	microgram per kilogram
µg/L	microgram per liter
mg/kg	milligram per kilogram
mg.L	milligram per liter
MRL	Missouri River Laboratory
msl	mean sea level
NAPL	non-aqueous phase liquid
NFA	No further action

ORP	oxygen reduction potential
PAH	polynuclear aromatic hydrocarbon
Part B Permit	RCRA Hazardous Waste Part B Permit No. CO-95-09-29-03
PCE	tetrachloroethene
PID	photoionization detector
ppm	parts per million
PQL	practical quantitation limit
PVC	polyvinyl chloride
QC	Quality control
QCSR	Quality Control Summary Report
QGMP	Quarterly Groundwater Monitoring Program
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
FRI Work Plan	Final RFI Work Plan for Landfill 2
RL	reporting limit
Rust	Rust Environment & Infrastructure
SAP	Sampling and Analysis Plan
SB	soil boring
SC	source water
SD	sediment sample
SP	poorly graded sand
SVOC	semivolaile organic compound
SWMU	Solid Waste Management Unit
TAL	target analyte list
TCE	trichloroethene
TDS	total dissolved solids
TIC	tentatively identified compound
TOC	total organic carbon
URS	URS Group, Inc.
USACE	United States Army Corp of Engineers
USAEHA	U.S. Army Enviornmental Hygiene Agency
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UTL	upper tolerance limit
UTL-A	upper tolerance limit – Alluvium
UTL-P	upper tolerance limit – Pierre Shale
VC	vinyl chloride
VOC	volatile organic compound

1

URS Group, Inc. (URS) prepared this Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) report for Landfill 2 (Solid Waste Management Unit [SWMU] 2) at the Fort Carson Military Reservation (Fort Carson), located just south of Colorado Springs, Colorado. This RFI report summarizes the two phases of RFI field activities (1994-1996 and 2004-2005) and presents the investigation results, including the nature and extent of contamination at Landfill 2. The report also discusses Landfill 2 investigations conducted prior to the RFI and other related Landfill 2 activities.

Historical records indicate Landfill 2 operated as a combined trench and area fill landfill between 1960 and 1978. Waste types placed in Landfill 2 included residential waste; mess hall wastes; office wastes; industrial wastes from motor pool operations, maintenance shop facilities, warehouses, print shops, and facility support shops; grit (sludge) from the preliminary treatment at the site Sewage Treatment Plant; and construction debris (SAIC 1994). Significant quantities of petroleum, oil, and lubricants were disposed at Landfill 2 (SAIC 1994). Landfill operations ceased in 1978 and the landfill was closed in accordance with the solid waste regulations in existence at that time.

Prior to Landfill 2 operation, wastes were disposed in areas known as Landfill 3 (SWMU 3), which were actively filled between 1957 and 1960. Waste disposal in these areas was discontinued after 1960 and Landfill 3 appears to have been completely covered by Landfill 2. With regard to this RFI report, the entire area encompassed by Landfills 2 and 3 is referred to as Landfill 2. In 1997 - 1998, waste consolidation activities were performed at Landfill 2, which modified the areal extent of waste. Waste was consolidated to facilitate the placement of a landfill cover as a short-term corrective measure.

The Landfill 2 RFI was conducted in two phases, with the first phase (1994-1996) determining waste extent, type and extent of landfill cover materials. The first phase also determined that sediment and surface water at the landfill was not impacted. The second phase (2004 - 2005) of the Landfill 2 RFI expanded on the first phase and evaluated the nature and extent of potential groundwater contamination and collected data for evaluating if human and ecological risks are associated with the site.

The RFI field activities focused on determining the areal extent of land filled wastes and the nature and extent of potential contamination in groundwater beneath and downgradient of Landfill 2. Activities conducted to determine the areal waste extent included a geophysical survey, field mapping, soil gas sampling, geotechnical borings, and trenching. Soil gas survey results identified the presence of hydrogen sulfide and methane, and measured total organic vapor concentrations. Soil boring results identified cover materials present over the 50-acre central portion of the 73-acre landfill, with a cover thickness ranging from four to 15 feet.

The results of groundwater monitoring at Landfill 2 indicate that there is not a laterally continuous water table beneath the landfill. The water table at the site is generally thin, seasonal, and probably flows into natural and artificial (the result of landfilling activities) drainage channels etched into the surface of the Pierre Shale bedrock. These bedrock channels constitute preferential groundwater flow pathways. Groundwater sampling analytical results identified several constituents at concentrations greater than their respective screening criteria, including nitrate, selenium, and volatile organic compounds (VOCs).

Monitoring well and direct-push groundwater samples collected during RFI activities were analyzed for VOCs, semivolatile organic compounds (SVOCs), nitrate, metals, and other constituents indicated in the Fort Carson RCRA Part B Permit (CDPHE 1995). Metals (antimony and manganese) were detected at concentrations above drinking water standards in groundwater near the southern (downgradient) edge of the landfill. Selenium was detected above the background concentration at many monitoring well locations. VOCs were detected at concentrations above Colorado Ground Water Standards (CGWS) in permanent and temporary monitoring wells. VOCs detected at concentrations above the CGWS include 1,2 dichloroethane; 1,2-dichloropropane; vinyl chloride; and benzene. The benzene concentrations were detected above CGWS numerous times in well 2492MW3. However, this well is located approximately 1,200 feet southwest of Landfill 2, adjacent to a vehicle maintenance facility. Although it was initially thought to be impacted by Landfill 2, the well is not hydraulically connected to Landfill 2 and has not been impacted by Landfill 2. Benzene was not detected within the Landfill 2 boundary, nor at any wells downgradient of Landfill 2 that are upgradient of other SWMUs. VOC concentrations found at and downgradient of Landfill 2 (but upgradient of other SWMUs) are probably the result of materials disposed of in the landfill.

The RFI investigation results have shown that nitrate concentrations at and downgradient of Landfill 2 may result from Sewage Treatment Plant sludge and additionally from the breakdown of other organic waste (mess hall waste) that was placed in Landfill 2. The nitrate concentration at the landfill is probably not related to the former Open Burn/Open Detonation area (SWMU 31) located approximately 400 feet southwest of Landfill 2. If there were saturated flow conditions across the site, this location would potentially be cross gradient to Landfill 2. Nitrate concentrations observed in groundwater farther downgradient of Landfill 2 and at other SWMUs located cross gradient to Landfill 2 indicate additional nitrate sources, such as naturally-occurring sources. The discussion presented in this RFI report suggests that in addition to the nitrate concentrations that may result from Landfill 2 waste, nitrate also is naturally-occurring at Fort Carson and the Landfill 2 area. This discussion also indicates that selenium is naturally-occurring in this area in the Pierre Shale bedrock.

This report presents the results of the RFI conducted at Landfill 2 (Fort Carson site number FTC-006) at Fort Carson. The Landfill 2 investigation was initiated as a voluntary investigation and later was included under the requirements of the Fort Carson Military Reservation RCRA Hazardous Waste Part B Permit No. CO-95-09-29-03 (Part B Permit) issued to Fort Carson by the Colorado Department of Public Health and Environment (CDPHE 1995). Landfill 2 is designated as SWMU 2 under the Part B Permit. The primary objective of the RFI was to characterize Landfill 2, including the nature and extent of contamination, if present. The investigation was conducted for the Fort Carson Directorate of Environmental Compliance and Management (DECAM) under various contracts between 1994 and 2005.

Fort Carson occupies approximately 220 square miles in central Colorado, adjacent to the eastern flank of the Rocky Mountain Front Range. The northern Fort Carson boundary is located in El Paso County, south of Colorado Springs (Figure 1-1). The southern boundary is approximately 10 miles north and parallel to U.S. Highway 50 in Pueblo County. A small area in the southwestern portion of Fort Carson is located in Fremont County.

Fort Carson is an active military training post with a primary mission to train, mobilize, deploy, and sustain combat ready forces. Principal industrial operations at Fort Carson include vehicle and aircraft repair and maintenance. As shown on Figure 1-2, Landfill 2 is located in the eastern portion of the Cantonment Area, located near the northern Fort Carson boundary. Landfill 2 is located within the SW ¼ of the SE ¼ of Section 15, Township 15 South, Range 66 West. A concrete drainage ditch is the only manmade structure currently within the landfill boundary. Landfill 2 is not currently in use.

1.1 PURPOSE AND SCOPE

As indicated above, the RFI was conducted to characterize Landfill 2, determine if contaminants are present, and determine the nature and extent of potential contamination. Groundwater, surface water, and sediment may have been adversely affected by waste disposal activities conducted from 1957 to 1978. The RFI objectives were to (Earth Tech 2001):

- Determine the landfill waste extent
- Determine the cover material thickness and characteristics
- Determine if adjacent surface water and sediments have been adversely affected by the landfill

- Determine if shallow groundwater is present below Landfill 2 and if groundwater beneath and downgradient of the landfill has been adversely affected by the landfill
- Determine the nature and extent of groundwater contamination, if present
- Determine the fate and transport of contamination, if present
- Collect data for future evaluation of human and ecological risk

The Landfill 2 RFI was conducted during two time periods. Initial RFI activities were completed from 1994 through 1996. These activities identified the waste extent and evaluated potential landfill impacts. Additional groundwater samples were subsequently collected at selected monitoring wells as part of the Fort Carson Quarterly Groundwater Monitoring Program (QGMP). A draft RFI Report was prepared in 2001 (Earth Tech 2001), but was not finalized nor provided to CDPHE. Additional RFI activities, focusing on groundwater, were conducted in 2004 and early 2005 based on the 2004 Earth Tech RFI Work Plan Addendum (Earth Tech 2004b). These activities were designed to supplement data collected from 1994 through 1996 and to determine if the landfill has impacted groundwater. The 1994-1996 Landfill 2 RFI and QGMP activities are referred to in this document as initial; the 2004-2005 activities are referred to in this document as supplemental. This report evaluates the Landfill 2 RFI data from both the 1994-1996 and 2004-2005 periods.

The purpose of this report is to present the RFI results with respect to the objectives listed above.

This report:

- Provides project description and history
- Summarizes previous investigations, RFI activities, and reporting requirements
- Presents RFI field and analytical results
- Assesses the nature and extent of contamination, as applicable
- Evaluates contaminant fate and transport, as applicable

1.2 REPORT ORGANIZATION

This RFI report is organized as follows:

- Executive Summary
- Introduction (Section 1)
- Site History (Section 2)

- RFI Activities (Section 3)
- RFI Results (Section 4)
- Nature and Extent of Contamination (Section 5)
- Constituent Fate and Transport (Section 6)
- Conclusions (Section 7)
- Recommendations (Section 8)
- References (Section 9)

Nine appendices are attached to this document. Appendix A presents historical aerial photographs. Appendix B presents correspondence relevant to the Landfill 2 RFI. Appendix C provides copies of borehole and field forms. Appendix D presents a summary of initial analytical data. Appendix E provides a quality control summary. Appendix F presents survey data. Appendix G presents the supplemental data results. Appendix H presents a summary of tentatively identified compounds. Appendix I presents geotechnical boring logs, geophysical survey results, and trench test pit reports.

The following section describes the operational and regulatory history of Landfill 2 and briefly describes previous environmental investigations performed at the site.

2.1 OPERATIONAL HISTORY

Landfill 2 encompasses approximately 73 acres. The landfill operated as a combined trench and area fill landfill, with trenches situated perpendicular to the topographic slope (Environmental Science and Engineering 1983). Waste placement in the trenches occurred below and above ground surface elevations, resulting in waste piles up to 20 feet above natural ground level. Temporary soil cover placed daily over the waste consisted of trench spoil material, from within Landfill 2 and hauled from other Fort Carson sites, with thicknesses varying from four to 15 feet.

The military used an area northwest of Landfill 2 for waste disposal, known as Landfill 3 (SWMU 3), from 1957 to 1960 (U.S. Army Environmental Hygiene Agency [USAEHA] 1988). Landfill 2 covers Landfill 3, with no apparent distinct boundary between the wastes. Landfill 2 operated from 1960 to 1978. This RFI report refers to both landfills as Landfill 2. Known wastes disposed at Landfill 2 include:

- Sanitary wastes from residential halls, mess halls, and offices
- Industrial wastes from motor pool operations, maintenance shop facilities, warehouses, printing shops, and facility support shops
- Construction debris
- Sewage Treatment Plant sludge

Industrial waste disposed at Landfill 2 included quantities of petroleum, oil, and lubricants. The quantities and nature of these wastes are not known. A temporary cover, composed of trench spoil material from various locations at Fort Carson, overlies approximately 50 acres of the landfill.

Historical aerial photographs illustrate the Landfill 2 operational history. Appendix A includes the photographs. The earliest available aerial photograph, dated 1947, depicts undisturbed ground at the Landfill 2 site. A 1963 photograph depicts waste placement activities and shows a large disturbed area and a haul road entering the landfill boundary from the southwest. The 1967 and 1970 aerial photographs depict increasingly larger disturbed areas, which may be sub-linear disposal trenches oriented from southwest to northeast. Historical aerial photographs do not specifically identify waste disposal areas. In the 1979 photograph, the disturbed areas appear to be covered and some revegetation had taken place. Figure 2-1 shows the extent of waste when operations ceased and the current waste extent. Table 2-1 summarizes the landfill operation history.

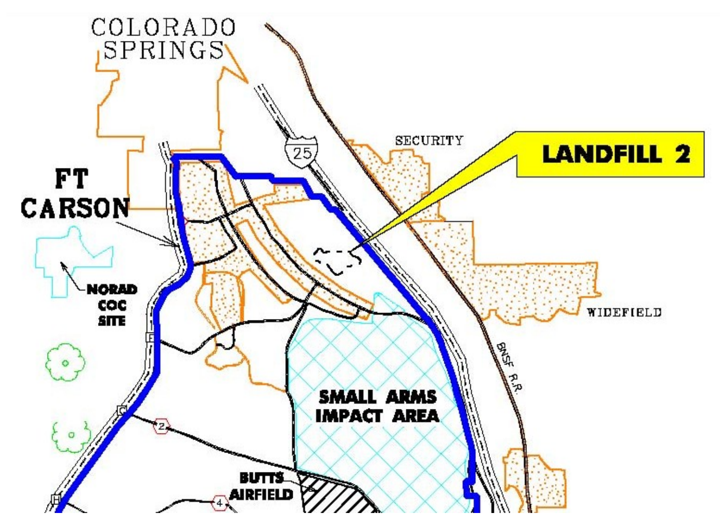
2.2 REGULATORY/REPORTING HISTORY

As indicated previously, Landfill 2 is identified as SWMU 2 and Landfill 3 is identified as SWMU 3 under the Fort Carson RCRA Part B Permit (CDPHE 1995). The Part B Permit requires that an RFI be conducted at Landfill 2/3 to determine if contamination is present or has been released from the landfills. The Part B Permit indicates the known or suspected constituents of concern to be addressed in the RFI. These constituents include SVOCs, VOCs, pesticides, herbicides, metals, explosives, and unexploded ordnance. The RFI activities discussed in this report were conducted under the permit requirements. Additional activities related to the regulatory history of the landfill are summarized in Table 2-1.

Numerous historical documents have been submitted to CDPHE by Fort Carson and Rust Environment and Infrastructure (Rust). These documents primarily discuss Landfill 2 studies and investigations. These documents are important to the RFI in terms of understanding the timeline and rationale for the Landfill 2 decision making process. The documents also indicate the operational and regulatory history of the landfill and are the sources of some of the information summarized in Table 2-1. Many of these documents are Sampling and Analysis Plans (SAPs) and Work Plans and, in addition to Landfill 2, reference other SWMUs and landfills in the vicinity. The documents are listed in Appendix B. Appendix B also includes additional correspondence between Fort Carson and the CDPHE regarding Landfill 2.

Table 2-1
Landfill 2 Operational and Regulatory History Summary

Summary	Landfill 2 is a 73-acre combined trench and area landfill. The landfill contains sanitary and industrial waste, construction debris, and sewage sludge. Landfill operations have ceased and the landfill has a vegetated soil cover.
Date	**Activity**
Prior to 1957	Landfill 2 area undisturbed
1957	Landfill 3 operations began
1960	Landfill 3 operations ceased, Landfill 2 operations began
1978	Landfill 2 operations ceased, landfill closed in accordance with existing solid waste regulations
1979	Landfill 2 area cover revegetation occurred
1981 – 1992	Initial environmental investigations
1992	Surface water control measure installed at Landfill 2
1994	Environmental Protection Agency completed RCRA Facility Assessment of Fort Carson (augmented in 1994 by CDPHE)
1994-1996	RFI (first phase) conducted
1995	RCRA Part B Permit effective
1997-1998	Landfill waste consolidated
1998-2000	Grading activities conducted to control surface water
2001	Draft RFI report written (not finalized)
2003	RCRA Part B Permit modified
2004-2005	RFI (second phase) conducted, CDPHE requested additional activities in September 2004



2.3 PREVIOUS ENVIRONMENTAL INVESTIGATIONS

Three environmental investigations were conducted at Landfill 2 prior to the RFI. These investigations yielded data used to initially characterize Landfill 2 and to identify potential adverse effects of landfill operations. The following sections summarize the investigation results related to Landfill 2. Two of the investigations (Sections 2.3.2 and 2.3.3) encompassed large areas of Fort Carson that included Landfill 2. Figure 2-2 shows the locations of monitoring wells installed during these investigations.

2.3.1 U.S. Geological Survey (USGS), Groundwater Monitoring Well Installation, 1981

The USGS installed three monitoring wells (FCMW75, FCMW78, and FCMW79) at Landfill 2 in 1981. The USGS did not publish a formal document on these activities. Therefore, information on the investigation intent and findings are not available. The wells were subsequently abandoned.

2.3.2 U.S. Army Environmental Hygiene Agency (USAEHA), Phase 2 Geohydrologic Study No. 36-26-0392-87, Fort Carson, Colorado, 1985

The USAEHA performed a geohydrologic study of Fort Carson, including Landfill 2, in 1984 that included well installation and groundwater sampling. The USAEHA installed four monitoring wells (FCMW74, FCMW77, FCMW80, and FCMW81) at Landfill 2 to identify impacts to water quality. The groundwater sampling results for these wells identified the presence of elevated total organic carbon (TOC), chemical oxygen demand (COD), sulfate, and nitrate in groundwater downgradient of Landfill 2. Although the investigation included sampling groundwater for VOCs, the sampling results did not identify elevated VOC concentrations in groundwater. The investigation results indicated Landfill 2 was impacting downgradient water quality, although USAEHA's report indicated Landfill 2 was not the cause of elevated nitrate concentrations in groundwater (USAEHA 1985). Wells FCMW80 and FCMW81 were subsequently abandoned.

2.3.3 USAEHA Ground-Water Quality Study No. 38-26-0897-89, Investigation of Closed Landfills, Fort Carson, Colorado, 1988

The USAEHA performed a groundwater quality study in 1988 that included well installation, groundwater sampling, slug testing, and a terrain conductivity survey. USAEHA installed 14 monitoring wells (wells FCMW61 through 73 and 76) downgradient of Landfill 2. Wells FCMW69 and FCMW76 have been abandoned. The groundwater sampling results identified the presence of elevated sulfate, COD, total dissolved solids (TDS), and nitrate concentrations. The study indicated that leaching from the Pierre Shale caused the high TDS and sulfate concentrations. The groundwater sampling results did not indicate the presence of VOCs (USAEHA 1988). The terrain conductivity survey identified higher soil conductivities located at the southern end of the landfill, which were thought to correspond to an area of leachate generation in Landfill 2. In 1992, USAEHA conducted further monitoring well sampling, which detected low concentrations of VOCs in groundwater samples from wells FCMW75, FCMW76 and FCMW78, located within waste fill areas. VOCs were not detected in any of the downgradient monitoring wells that were sampled. The 1992 sampling results indicated high TDS, COD, and sulfate concentrations (USAEHA 1992).

These investigations provided initial characterization of Landfill 2. They also indicated certain constituents may be naturally occurring (TDS, sulfate, and nitrate). The RFI expanded on the initial characterization data from these investigations and the RFI data substantiate or refute the initial findings or potential Landfill 2 impacts, as discussed in Section 5.

This section restates the RFI objectives and summarizes the RFI field activities. Variations from the RFI Work Plan and Work Plan Addendum that occurred during implementation of the work are found in Appendix E-1, Section 2.

3.1 RFI OBJECTIVES

Landfill 2 RFI investigative activities were designed to fulfill the RFI objectives listed in Section 1, including assessing the nature and extent of contamination present in groundwater beneath and downgradient of Landfill 2. The RFI investigations were conducted in accordance with the following documents:

- Revised Final Sampling and Analysis Plan for Remedial Design, Landfills 2, 5, and 6, and Vapor Degreasing/Spray Jet Washers (Rust 1995d)
- Field and Laboratory Procedures Manual [FPLM, (Rust 1997 and 1998c)]
- Final RCRA Facility Investigation Work Plan Addendum, Landfill 2 (Earth Tech 2004b)

The investigation design and implementation were in accordance with CDPHE and Colorado Water Resources Division Regulations. The RFI was conducted in accordance with Part IV of the Part B Permit (CDPHE 1995) and Colorado Hazardous Waste Regulations. The RFI objectives were to:

- Determine the landfill waste extent
- Determine the cover material thickness and characteristics
- Determine if adjacent surface water and sediments have been adversely affected by the landfill
- Determine if shallow groundwater is present below Landfill 2 and if groundwater beneath and downgradient of the landfill has been adversely affected by the landfill
- Determine the nature and extent of groundwater contamination, if present
- Determine the fate and transport of contamination, if present
- Collect data for future evaluation of human and ecological risk

The investigation results provide data sufficient to assess the risk to human health and the environment, as required by Section IV.G.3.C of the Part B Permit. If necessary, a Corrective Action Plan (CAP) or a Corrective Measures Study (CMS) will be prepared based on the investigation results.

3.2 SUMMARY OF 1994-1996 RFI ACTIVITIES

As previously discussed, initial Landfill 2 RFI activities occurred between 1994 and 1996. The 1994 investigation included a site reconnaissance and a site geophysical survey. Site topographic maps, prepared in early 1995 by Aero-Metric, were created from aerial photographs taken on 14 December 1994. Preliminary field mapping, performed in April 1995 prior to intrusive investigations, established the approximate waste extent. In 1995, a soil gas survey was completed and 14 geotechnical borings were advanced (SB-1 through SB-14) to obtain data for the existing landfill cover and to identify the type and location of waste materials. During the 1995 investigation, two direct-push groundwater samples and groundwater samples from six existing monitoring wells were collected. The analyte list used for the sample analyses was based on the list contained in the Part B Permit.

During 1996, a second phase of the geotechnical investigation advanced 29 shallow, cover verification, and test borings (CVT-1 through CVT-29), the locations of which are unknown. Results from trenching performed in 1996 refined the known extent of waste at Landfill 2. The 1996 investigation also involved the collection and analyses of four sediment samples from drainage ditches and six direct-push groundwater samples. The sampling activities are discussed in more detail below. Table 3-1 (referenced from Earth Tech 2001) summarizes the 1994-1996 groundwater sampling activities. Table 3-2 (referenced from Earth Tech 2001) summarizes the 1994-1996 sediment sampling activities.

The 1994-1996 activities met the following RFI objectives:

- Determined waste extent
- Determined landfill cover material thickness and characteristics
- Determined that some groundwater present near Landfill 2

3.2.1 Existing Well Identification

RFI investigation preparation activities included physically locating existing groundwater wells near Landfill 2. Inspection of these wells, including FCMW61 through FCMW68 and FCMW70 through FCMW81, took place in February 1995. The depth to water, total well depth, and condition of the wells for future groundwater sampling were determined during the inspections. Existing groundwater monitoring wells were sampled during the RFI investigation to identify contaminants of concern affecting groundwater at Landfill 2. Well FCMW69 had been abandoned and no water was present in well FCMW77. Table 3-3 summarizes the existing well construction information. Appendix C contains additional well construction information. Figure 2-2 shows the location of existing and abandoned wells at Landfill 2.

3.2.2 Geophysical Survey

The geophysical survey, conducted in December 1994 to determine the waste extent, defined the outer perimeter of Landfill 2. Geo-Centers conducted the geophysical survey using a Geonics EM31 continuous wave electromagnetic sensor. In general, the survey was not able to refine the Landfill 2 boundaries beyond the boundaries determined from the field mapping effort. Although some in-phase data appeared to correlate with metal observed at the ground surface, data analysis provided minimal information on identifying the waste extent. Poor correlation was probably the result of the large amount of soil mixed with the waste materials, as noted during the completion of the geotechnical borings, which are discussed bellow (Rust 1996e). Appendix I presents geotechnical boring logs, and geophysical survey results.

3.2.3 Soil Gas Survey

A soil gas survey was performed at Landfill 2 during May and June of 1995 to evaluate hydrogen sulfide, methane, and total organic vapor concentrations. The procedure used to collect the soil gas survey consisted of driving a gas sampler as discussed below:

- The steel tip was placed onto the end of a 5-foot hollow steel rod, a slide hammer was attached to the steel rod and the steel rod was hammered into the soil to a 3.5 – 4.0 foot depth
- The steel rod was pulled upward 2 to 3 inches towards the ground surface
- The slide hammer was removed from the steel rod and a tygon tubing/tee assembly/sample vacuum bulb were attached
- The tubing was filled with the soil gas using a vacuum bulb
- The tygon tubing was attached to each instrument individually and the soil gas measured (methane, hydrogen sulfide, and total organic vapors)
- The slide hammer was placed back onto the steel rod, and the steel rod was removed from the soil.

Additional monitoring included passive soil gas pressure measurement and applied vacuum measurement. These parameters were measured immediately after the methane, hydrogen sulfide, and total organic vapor gas analyses at each location.

Over 100 points were surveyed for Landfill 2 for landfill soil gas using the procedures described above. Results of the soil gas survey revealed small concentrations of methane, hydrogen sulfide in localized areas of the landfill. Concentrations of total organic vapors and hydrogen sulfide were below background levels. During the course of the survey work, personnel performing the survey did not observe odors typically associated with landfill gas. In addition, pressure measurements during the survey indicated that there was no positive pressure at any sampling point.

3.2.4 Soil Borings

The 14 geotechnical borings, advanced at Landfill 2 in June 1995, provided physical characteristics of Landfill 2 cover materials and assisted in waste identification. Boring locations included anticipated waste areas and areas where the waste extent was unknown. Borings were terminated when waste material was confirmed or bedrock was encountered. Soil boring depths ranged from six to 22.5 feet below ground surface (bgs). Soil boring results indicated the presence of cover materials at depths ranging from four to 15 feet, over the central, approximately 50-acre, portion of Landfill 2. The cover material primarily consists of lean clay with sand and sandy lean clay. The material, likely derived from local sources of alluvium and Pierre Shale, is stiff, brown to dark gray/brown, moist, medium plastic, and contains randomly oriented angular clasts of shale. The additional 29 shallow geotechnical borings were advanced in 1996 to obtain data on the existing cover soil type, thickness, and permeability. Additional investigation activities in 1999 were conducted to collect data for the evaluation of using the existing cover as an evapotranspiration (ET) cover. Appendix I contains the geotechnical boring logs.

3.2.5 Direct-Push Water Sampling

Direct-push groundwater sampling was conducted at Landfill 2 in June 1995 at locations LF2DPW1 through LF2DPW5. These locations were selected to provide additional data between existing monitoring well locations. Muddy conditions and shallow bedrock made sampling impossible at LF2DPW1 and LF2DPW5. Groundwater was not encountered during two direct-push sampling events at location LF2DPW2. Figure 2-2 shows the direct-push sample locations.

Additional direct-push groundwater samples were collected in March 1996. Sample results for LF2DPW6 through LF2DPW12 confirmed the extent of metal concentrations above screening criteria that were found in monitoring wells FCMW75 and FCMW76. These results also confirmed the extent of VOC concentrations detected in FCMW76. Additional direct-push sampling locations included natural drainage swales. Location LF2DPW10 only provided a sufficient volume of groundwater to obtain a sample for VOC analysis. Table 3-1 (referenced from Earth Tech 2001) also summarizes the direct-push groundwater sampling activities.

3.2.6 Borehole Abandonment

Boreholes advanced by direct-push sampling or auger drilling were abandoned in accordance with State of Colorado Water Resources Division and USACE requirements. Appendix C contains the Landfill 2 RFI borehole abandonment reports.

3.2.7 Trenching

Trenching performed at Landfill 2 in February 1996 obtained data to determine the waste extent. Figure 3-1 shows the locations of 24 trenches (LF2T01 though LF2T24) excavated around the Landfill 2 perimeter. Trench excavation began at the landfill perimeter and continued towards the landfill interior. A trench was terminated once waste or native material was encountered at the landfill perimeter. The total depth of fill was estimated when native material was encountered. A discontinuous trenching method was employed for trench LF2T24 because of the trench length. This method required excavation of several 10-foot sections extending towards the Landfill 2 exterior, until waste was encountered. The excavation of four extension trenches (LF2T02a, LF2T02b, LF2T03a, and LF2T20a) identified the waste extent and thickness near the southwest corner of Landfill 2. Appendix I contains the trench test pit report. A field engineer observed and directed the backhoe operator during trench excavation.

Landfill 2 waste consolidation, performed in 1997 - 1998, modified the waste extent, and assisted in the placement of the existing cover. Figure 3-1 shows the existing extent based on survey results after landfill cover placement.

3.2.8 Sediment Sampling

During 1996, sediment grab samples were collected from the drainage ditches adjacent to Landfill 2. These drainage ditches convey surface water runoff following intense storm events. During sampling, surface water was not present in the ditches and no surface water samples were collected. The sediment sample depth was zero to six inches and the sample color and type was recorded. The sediment sample sites were allowed to fill in naturally after sampling. Table 3-2 (Earth Tech 2001) summarizes the sediment sampling and analyses conducted.

The sediment results also serve as results for surface water, because surface water is rarely present and the sediment would contain unvolatilized organic constituents and any inorganic constituents that remained after surface water flow had dissipated.

Soil sampling was not performed because there was no native soil below Landfill 2. The material beneath the landfill consists of weathered Pierre Shale bedrock.

3.2.9 Source Water Sampling

Source water samples were collected and analyzed as part of site investigations and the QGMP to confirm that water used for decontamination and other investigative activities did not contain constituents that could adversely affect the results of the Landfill 2 RFI. Subcontractors obtained water for use during RFI field activities for Landfill 2 from two source water access points at the installation. Fort Carson personnel identified water taps at Building 1399 (sample 1399CS) and at Building 1304 (sample 1304CS). These taps access the City of Colorado Springs water supply.

Multiple samples were collected from the tap at Building 1399 and analyzed as part of the QGMP and other RFI activities. The source water samples from Building 1399 were collected directly from a hose connected to the source water discharge point. Multiple samples were collected from the tap at Building 1304 and analyzed as part of the QGMP and other RFI activities. The source at Building 1304 consists of a high-flow overhead hose typically used for filling large tanks. Methods and procedures as described in section 2.15.2 of the FLPM (Rust 1997 and 1998) were applied during sample collection from these source water points. Table 3-4 summarizes the source water analyses conducted.

3.3 SUMMARY OF 2004-2005 RFI ACTIVITIES

As indicated previously, a Draft RFI Report (Earth Tech 2001) was prepared that summarized the 1994-1996 RFI fieldwork. The report was not finalized nor was the report submitted to CDPHE, pending the completion of additional investigation activities. As discussed in the Final RFI Work Plan Addendum (Earth Tech 2004b), the additional investigation activities were proposed to supplement the 1994-1996 RFI results. More specifically, the objectives for the additional investigation activities were to:

- Determine whether Landfill 2 has impacted groundwater beneath the landfill and/or downgradient of the landfill
- Identify the nature and extent of organic and inorganic constituents in groundwater upgradient, downgradient, and cross gradient of Landfill 2
- Refine the interpretation of the groundwater flow regime in and adjacent to Landfill 2

During 2004, seven new monitoring wells (LF2MW01 through LF2MW07) were installed around the Landfill 2 boundary. Groundwater samples were collected from the new wells and select existing wells in the Landfill 2 area. Eleven direct-push temporary monitoring wells (LF2DP13 through LF2DP23) were also installed around Landfill 2 to determine the presence of groundwater. The new monitoring and direct-push wells that contained water, as well as existing monitoring wells that were listed in Section 3.0 of the Final RFI Work Plan Addendum (Earth Tech 2004b), were sampled and the samples submitted for laboratory analyses. The work was conducted in accordance with the Final RFI Work Plan Addendum (Earth Tech 2001), with no significant deviations. Table 3-5 summarizes the groundwater sampling activities. Results are discussed in Section 4.0 and summarized in tables presented in Section 4.0.

The work plan did indicate that additional permanent monitoring wells could be installed and sampled, based on the presence of water in the direct-push wells. To determine the presence of water, water levels were measured in the new monitoring and direct-push wells on 3 August 2004. Only four of the monitoring wells (LFMW03, LF2MW05, LF2MW06, and LF2MW07) and three of the direct-push wells (LF2DP13, LF2DP14, and LF2DP18) contained water. Water levels were again measured on 25 August 2004 and again only the four monitoring wells listed above contained water. Only three direct-push wells (LF2DP13, LF2DP17, and LF2DP18) contained water.

In August 2004, DECAM communicated the water-level measurement findings to CDPHE and discussed the need to install additional permanent monitoring wells and/or conduct additional fieldwork. Based on this communication, DECAM and CDPHE decided on 28 September 2004 that additional work should be conducted. The DECAM and CDPHE additional work decisions are documented in an e-mail series included in Appendix B. The decision was made to:

- Collect grab water samples from LF2DP17 and LF2DP18 (if adequate water) and submit the samples for nitrate and VOC analyses
- Overdrill LF2DP13 and replace it with a new permanent monitoring well (LF2MW08)

- Sample LF2MW08 for the full analytical suite, including explosives by EPA Method 8330
- Measure the water level in well FCMW77
- Abandon the direct-push wells

Monitoring well LF2MW08 was installed and subsequently sampled in January 2005. The 2004-2005 RFI activities concluded in January 2005 with the LF2MW08 sampling, laboratory analysis, and surveying the well casings to determine groundwater elevations.
The 2004 – 2005 activities met the following RFI objectives:

- Determined presence of groundwater
- Determined potential impacts to groundwater
- Determined nature and extent of contamination as applicable

3.4 PROJECT PROCEDURES

The following sections discuss the procedures used to conduct the 1994-1996 and 2004-2005 RFI activities.

3.4.1 Site Clearance

Prior to site mobilization, the investigation areas were cleared for underground utilities and structures. Utility clearances were conducted by Fort Carson personnel, utility clearance companies, and utilities in the Colorado Springs area. The following organizations were notified at least two weeks prior to scheduled subsurface activities so that the locations of utilities beneath the pavement, concrete, or ground surface near the investigation sites could be determined:

- Fort Carson personnel (Directorate of Public Works)
- Utility Notification Center of Colorado
- City of Fountain
- Fountain Valley Fry-Ark Line
- Stratmoor Hills Water District

As-built site plans, provided by the USACE, were also checked for utility locations. Drilling locations were field adjusted, as necessary, to avoid overhead and underground utilities and obstructions

3.4.2 Field Equipment Calibration

Calibration and maintenance of the PID, explosive gas meter, pH meter, conductivity meter, turbidity meter, and water level measuring device used during the RFI was performed on a daily basis. Calibration and maintenance of the field equipment was conducted in accordance with the manufacturer's instructions and the procedures outlined in the FLPM (Rust 1998c). Prior to using the equipment, each device was checked to confirm it was in working order.

3.4.3 Field Work Documentation

The field activities were documented in permanent ink using the following forms:

- Daily Report
- Daily Quality Control Report (DQCR)
- RFI Drilling Log
- Headspace Testing for Volatiles Log
- Well Development Record
- Water Level Data Summary
- Groundwater Sample Collection Log
- Chain of Custody (COC) Record
- Direct Reading Instrument Log
- Borehole Abandonment Record
- Landfill Trenching Log
- Soil Gas Survey Log

A Daily Report was maintained throughout each day, and a DQCR was completed daily. The DQCRs are included in Appendix E. Copies of these two forms, with attached Health and Safety forms, updated site maps, boring logs, analytical data, and COC forms were faxed daily to the Earth Tech Project Manager. The DQCRs and Daily Report forms were faxed daily to the USACE Technical Manager for review and comment. The original signed forms were delivered weekly to the Earth Tech Project Manager. A package of information was submitted to the USACE on a weekly basis. The package included DQCRs, records of communication, and boring logs for the preceding week.

COC documentation was initiated as samples were collected. Project personnel maintained sample custody until samples were relinquished for shipment to the analytical laboratory. Custody documentation was confirmed at the subcontract laboratory upon receipt of the samples.

3.4.4 Management of Investigation Derived Waste (IDW)

Wastewater generated during the RFI, including decontamination, well development, and purge water, was containerized in new or dedicated 55-gallon drums. The liquid waste was disposed in the Fort Carson Industrial Wastewater Treatment Plant system after RFI sample analytical results indicated the treatment plant influent standards had been met. Soil cuttings and discarded soil samples were placed in reconditioned Department of Transportation (DOT) approved 55-gallon drums. During the 1994-1996 RFI activities, if the waste was determined not to be a characteristic hazardous waste; it was disposed of by Fort Carson at the on site Subtitle D landfill. The non-native trenching waste material was containerized in reconditioned DOT approved 55-gallon drums. This material was incorporated into the subgrade during the waste consolidation activities during late 1997 and early 1998, and it was anticipated the material would ultimately be overlain by a landfill cover. During the 2004-2005 RFI activities, IDW was disposed offsite. Personal protective equipment, plastic sheeting, disposable bailers, and other sampling derived wastes were containerized separately and disposed offsite as non-hazardous waste.

3.4.5 Surveying

The existing monitoring wells and geotechnical soil borings were surveyed by Montgomery Phillips, Inc. in July 1995. Sediment, soil gas, and direct-push groundwater sample locations were not surveyed. Rather, they were approximately located for reporting purposes. The trench locations and areal waste extent was surveyed by Leigh Whitehead in February 1996. In August 2004 and January 2005, Montgomery Phillips surveyed the monitoring wells installed in 2004. The surveying performed by both contractors was performed under Registered Land Surveyors, licensed in the State of Colorado. The 2004 direct-push sampling locations were located by Earth Tech using a global positioning system.

The coordinates and ground surface elevations, as well as the elevations of the top of the polyvinyl chloride (PVC) well casing, were determined to the closest 0.01 foot vertically and 1 foot horizontally. The surveyed coordinates were referenced to the North American Datum of 1983 and the Colorado State Plane Coordinate system, and the elevations were referenced to the National Adjusted Vertical Datum of 1988. A permanent reference point was marked on the PVC riser pipe of each monitoring well for subsequent groundwater level measurements. Survey data were recorded in the Monitoring Well Log Book by Earth Tech personnel upon survey completion. Landfill 2 survey data are included in Appendix F.

3.4.6 Sample Labeling, Handling, and Shipping

Each groundwater, soil, and sediment sample was labeled with a unique identification number consisting of a site identifier, sample type identifier, sample location number, and optional quality control (QC) suffix:

- Site Identifier
  LF2 Landfill 2
  FC Fort Carson
  1304 Building 1304 (i.e., for source water sample location)

- Sample Type Identifier
  MW Monitoring Well
  DPW Direct-push Water Sample
  SD Sediment Sample
  SB Soil Boring
  SC Source Water

- Sample Location Number
  A unique sequential number was used to identify each sampling location

For groundwater samples collected from an existing well, the well name was used (e.g., FCMW76). For the RFI sampling, six split samples were sent to the USACE Missouri River Laboratory (MRL) with the MRL Information Management Systems Project Identification Number of 3086. This identification number was also indicated on the COC form.

Samples were shipped daily in coordination with the analytical laboratories to meet analysis holding times. Laboratory sample receipt procedures were followed by each of the laboratories.

3.4.7 Decontamination Procedures

Augers and downhole tools used for drilling were decontaminated using potable water (source water) supplied by Fort Carson. Decontamination was accomplished using a mobile decontamination rig that included a steam cleaner and a trough that collected the decontamination water, which was then transferred into new 55-gallon drums.

Smaller equipment, such as direct-push probe pipe, stainless steel bowls, water level measuring devices, and reusable bailers, were decontaminated between each use with a non-phosphate laboratory detergent and potable water wash with a brush, followed by a potable water rinse and deionized water rinse. When possible, small equipment was steam cleaned in place of the detergent wash and rinse. Following decontamination, sampling equipment was wrapped in aluminum foil or stored on a clean surface to prevent recontamination.

The following sections discuss field observations, site-specific geologic and hydrogeologic characteristics, and field and analytical results for Landfill 2. Additional detailed information regarding the physical characteristics of Fort Carson is provided in Section 2.3 of the Final RFI Report, Grit/Oil Pit (Earth Tech 2000).

4.1 CLIMATE

The climate at Fort Carson is characterized as mid-latitude semiarid with hot summers, cold winters, and light rainfall. The average daily temperatures range from 28.8 degrees Fahrenheit (ºF) in January to 71.2 ºF in July. The area receives an average precipitation of 15.42 inches per year, with approximately 80 percent occurring between April and September. The annual snowfall averages 43 inches per year, with the heaviest snowfall occurring during March. A wind rose of the meteorological data collected during 1984 at Fort Carson showed that 95 percent of the winds were 10 knots or less and that the greatest frequencies of winds over 10 knots were east-northeast and west-southwest (HQ Fort Carson 1988).

4.2 TOPOGRAPHY AND PHYSIOGRAPHY

Fort Carson is situated within two physiographic provinces; the eastern part is located in the Colorado Piedmont section of the Great Plains Province and the western part is located in the Rampart Range foothills section of the Southern Rocky Mountains Province. The Colorado Piedmont in this area is characterized by eastward-sloping plains, which are dissected by tributaries to Fountain Creek. The west-central part of Fort Carson is semi-mountainous with steep hills, shallow steep-walled canyons, and gently rolling uplands.

Landfill 2 is approximately 1,000 feet long from north to south, and approximately 3,000 feet wide from east to west. The relief at the Landfill 2 site is approximately 100 feet; the main portion of the landfill is relatively flat and gently sloping to the south. The elevation is approximately 5,900 feet above mean sea level (msl) at the northwest and northeast corners of the landfill and along the northern boundary. The elevation is approximately 5,800 feet above msl in the far southeast and southern portions of the landfill. A topographic high (approximately 5,940 feet above msl) is located just south of the northeast corner of the landfill, adjacent to the eastern landfill boundary.

4.3 LANDFILL WASTE

The waste encountered during trenching activities at Landfill 2 consisted mainly of soil filled with glass, metal, wood, plastic, brick, concrete, and paper. These debris descriptions are consistent with the historical accounts of landfill activity in the early 1970s. Sewage sludge and petroleum related wastes were not encountered during these activities. These wastes may have been placed towards the interior of Landfill 2 where trenching activities did not intersect them. Total thickness of waste ranged between approximately 2 feet to 6 feet. Waste consolidation performed in 1997 - 1998 modified the waste extent. Waste located on the eastern areas outside the perimeter surface water channel and the slope north of the surface water collection channel was relocated to the landfill interior during cover amendment. A landfill footprint has been identified based on the results of the Landfill 2 RFI investigation.

4.4 VEGETATION

The vegetation on the landfill is approximately 100 percent established. Native grasses constitute the dominant growth across the landfill surface; however, yucca, prickly pear, and many varieties of weeds are monopolizing bare areas.

4.5 GEOLOGY

Soils encountered during the RFI investigation were classified using the Unified Soil Classification System (USCS) as described by the American Society for Testing and Materials (ASTM) (ASTM 1994a, 1994b).

Alluvial material, consisting of Piney Creek Alluvium and Post-Piney Creek Alluvium, was encountered in the topographically low southeastern portion of Landfill 2 (borings SB-12 and SB-13). The composition of the alluvium varied considerably, ranging from poorly graded sand (SP) to high plasticity fat clay (CH) with occasional lenses of sandy lean clay (CL). Colluvium encountered in the northwestern portion of the landfill (SB-4 and SB-5) generally consisted of medium plasticity sandy lean clay. In some cases, the colluvium contained subangular gravel and salt-like nodules. The thickness of alluvium/colluvium and, correspondingly, the depth to bedrock ranged from 6 – 17 feet at Landfill 2.

The bedrock beneath Landfill 2 consists of Pierre Shale (Trimble and Machette 1979). The condition of this typically olive-grey material, deposited in a marine environment, varies from unweathered to severely weathered. The Pierre Shale is essentially flat lying (horizontal) at

Landfill 2; the unweathered to slightly weathered material is typically soft and plastic with thin laminae (less than 0.1 inch). Vertical fractures and heavy iron-oxide staining were noted in highly weathered Pierre Shale (SB-11); described in soil terms as lean to fat clay with varying fine sand content. Some of the vertical fractures are filled with white precipitate and crystals, probably gypsum.

Generally, the weathered Pierre Shale bedrock at Fort Carson occurs as hard, moist to occasionally saturated, predominantly fat clay (medium to high plasticity), with occasional lenses of fine sand. In most cases, the unweathered Pierre Shale bedrock is tight and competent.

Figure 4-1 presents the elevation of the bedrock surface beneath Landfill 2 and indicates that the bedrock surface generally slopes to the south and southeast. Table 4-1 presents the data used to construct the bedrock surface map. The map should be used as a general guide as few bedrock surface elevations directly beneath the landfill are known. Professional judgment was used in the field by various geologists and engineers in identifying the surface of the Pierre Shale in split spoon samples and auger cuttings from monitoring wells, direct-push borings, and geotechnical borings; and professional judgment was used by the individual interpreting the data and creating the map. The map provides an approximate elevation and identifies the major areas of relief in the bedrock surface within 500 feet of Landfill 2. However, the map does not identify the subtle bedrock preferential pathways that are discussed in Section 4.6.2 below.

4.6 HYDROLOGY AND HYDROGEOLOGIC CONCEPTUAL MODEL

A hydrogeologic conceptual has been developed to aid in evaluating the groundwater flow regime at Landfill 2, and the potential Landfill 2 impact to groundwater.

4.6.1 Surface Water Hydrology

Surface water drainage in the vicinity of Landfill 2 is a combination of sheet flow and dendritic intermittent streams fed by high intensity, generally short duration, spring snowmelt and summer showers and thunderstorms. Surface soils in the vicinity of Landfill 2 have a high runoff coefficient, which, in general terms, is the measured surface runoff volume divided by the measured rainfall volume. Figure 4-2 presents the hydrologic model of Landfill 2.

4.6.2 Hydrogeologic Conceptual Model

Shallow groundwater, when encountered at Landfill 2, is generally at depths ranging from 4 to 30 feet bgs. Previous work has described the occurrence of groundwater in the severely weathered portion of the Pierre Shale. Groundwater has not been observed in the unweathered Pierre Shale, probably because the small amount of recharge water and seasonal groundwater flux available drains off the unweathered bedrock surface before it has a chance to percolate into the extremely low hydraulic conductivity material.

Based on the results of monitoring well and direct-push well installations, water level measurements, and field observations, a hydrogeologic conceptual model for Landfill 2 has been developed. The model was developed to aid in evaluating the groundwater flow regime and potential Landfill 2 impacts. The RFI investigation results indicate that a laterally continuous water table does not exist at the site. A few locations along the southeastern landfill boundary have a substantial saturated thickness, a few locations appear to have a thin saturated thickness, and many locations appear to have a complete inability to produce groundwater.

The groundwater monitoring data does not allow for development of a potentiometric surface map for Landfill 2 because many locations appear to be unsaturated. Based on the configuration of the topography at Landfill 2, if a continuous water table were present beneath the landfill, the predominant direction of flow would be to the south, with a slight southeasterly component. Figure 4-3 depicts an August 2003 potentiometric map of the area downgradient of Landfill 2. This map presents a valid interpretation of the downgradient flow direction(s) for the date monitored. Professional judgment was used to interpolate between widely spaced monitoring locations. Table 4-2 presents the groundwater level data from 1994 through 2005.

Surface soils at the landfill have a high runoff coefficient (i.e. they are generally clayey) and the landfill is at a relatively high topographic location with respect to the surrounding land surface. Therefore, there is probably very little infiltration of precipitation, high evaporation, and very little recharge to groundwater. Water that does infiltrate encounters a lower, confining boundary that consists of the surface of the Pierre Shale. Groundwater then flows along the surface of the Pierre Shale and is directed into natural, generally south trending channels etched into the bedrock surface, which constitute preferential groundwater flow pathways typical of Fort Carson upland geology. The natural preferential pathways may consist of no more than subtle topographic lows on the surface of the Pierre Shale, which resulted from the overland flow of precipitation and snowmelt exploiting slightly lower plasticity, sandy zones along the bedrock surface. In addition, landfilling activities were accomplished by filling trenches, excavated into the Pierre Shale, that were oriented perpendicular to the topographic slope. These cuts also act as preferential flow pathways and probably aid in directing groundwater flow towards the natural bedrock drainages. Because of this, the majority of waste is probably not saturated.

Aerial photographs, particularly the 1967 and 1970 photographs, show relatively large areas of soil disturbance oriented southwest to northeast, which may consist of a series of sub-linear waste disposal trenches. Because topographic relief drops off to the south and east, these trenches may have constituted a series of waste disposal terraces. This configuration may be responsible for the fact that the eastern boundary of the landfill has the only contiguous area of groundwater saturation. During the August 2004 groundwater monitoring event, four monitoring wells were found to have a saturated thickness between nine and 15 feet at the southeastern boundary of the landfill (LF2MW05, LF2MW06, LF2MW07, and LF2DP13). In addition, well FCMW74, located approximately 350 feet south of well LF2MW05, had a saturated thickness of approximately 24 feet. Only three other monitoring wells around the entire landfill perimeter contained water during this monitoring event (LF2MW03, LF2DP17, and LF2DP18); none of these had a saturated thickness greater than 1.3 feet.

The geotechnical trenches excavated during RFI activities were of relatively short lengths, adjacent to or only penetrating the landfill perimeter until native material or waste was encountered and, therefore, do not provide for additional preferential flow pathways in the surface of the Pierre Shale.

Previous piezometer (slug) test data were used to estimate hydraulic conductivities at Landfill 2. Hydraulic conductivities ranged from 1.22×10^{-6} centimeters per second (cm/sec) at monitoring well FCMW74, to 2.08×10^{-3} cm/sec at monitoring well FCMW75 (SAIC 1994). Based on a review of historic boring logs and well completion information, monitoring well FCMW74 is completed in weathered shale, and monitoring well FCMW75 is completed in clayey silt (probably alluvium). The hydraulic conductivities calculated from the slug tests at these locations are appropriate for the materials logged for the completion zone of each well. The increased saturated thickness at well FCMW74 may be in response to the low hydraulic conductivity at that location.

An insufficient number of wells with a measured water level does not allow construction of a meaningful potentiometric surface map of the landfill. The extent of contamination will be limited to the preferential pathways, some portion of which are identified by monitoring well locations that are able to produce groundwater.

In summary, Landfill 2 has surface soils that allow for high runoff and little infiltration. Therefore, there is little groundwater flow beneath the landfill except for isolated preferential pathways etched into the Pierre Shale bedrock. The preferential pathways tend to diminish to the south of the landfill as the topography flattens and downgradient monitoring wells would intercept any available groundwater

4.7 FIELD AND LABORATORY RESULTS

Samples collected during the RFI were submitted to off-site fixed-based laboratories except for soil gas field screening samples, which were analyzed on site with a PID. Table 4-3 presents the analytical methods used for the Landfill 2 RFI. Figure 2-2 shows the RFI sampling locations. Historic groundwater and sediment analytical results are presented in Appendix D as Tables D-1 and D-2, respectively. Groundwater analytical results for the 2004-2005 Landfill 2 RFI activities are contained in Appendix G. Appendix H contains the VOC tentatively identified compounds (TICs) tables.

Analytical samples were collected in accordance with the FLPM (Rust 1997 and 1998) and proposed investigation strategies as detailed in the Final RFI Work Plan Addendum (Earth Tech 2004b). Detected concentrations are compared to their respective screening criteria in the following sections. The respective screening criteria are found in Appendix D. To further define the data usability, a discussion of (J) and (B) flags can be found in the QCSR, which is included as Appendix E.

4.7.1 Screening Criteria

Constituents detected in laboratory-analyzed samples were compared to the screening criteria to evaluate the nature and extent of contamination. The screening criteria for groundwater and sediment are discussed below. Screening criteria are not available for soil gas and source water samples. Therefore, no comparisons were performed for these samples types.

4.7.1.1 Groundwater Screening Criteria

The screening criteria used for groundwater result comparison consisted of the CGWS (5 CCR 1002-41, Tables A, 1, and 3) (CCR 2005) and approved risk based concentrations (RBCs) (Earth

Tech 2003a). The CGWS consist of Primary Standards (CGWS-P) and Agricultural Standards (CGWS-A). The most conservative standard was used for comparison to groundwater results to identify areas with potential impacts from site activities. For analytes with no CGWS, approved RBCs were used as the screening criteria. The RBCs were not used for analytes with CGWS. The Secondary Drinking Water Standards were not used as screening criteria.

In addition to the CGWS and RBCs, background concentrations for inorganic constituents in groundwater were also used as screening criteria, as contained in the Final (Approved) Risk-Based Evaluation Procedures Manual, Module II, Sitewide Background Data Set for Groundwater, Fort Carson, Colorado (Earth Tech 2003c). If the background concentration was greater than the CGWS, the background concentration was used for screening and noted as background, above regulatory criterion [BR(ARC)] on the results summary tables to indicate background above regulatory criteria. Otherwise, the background criteria were noted as BR.

4.7.1.2 Sediment Screening Criteria

Regulatory levels were not available to evaluate organic and inorganic constituents detected by laboratory analyses in sediment samples. However, soil screening criteria site-specific to Fort Carson were available as screening tools. These criteria included groundwater protection levels (GPLs), human health RBCs for organic and inorganic analytes, as well as background concentrations for inorganic analytes in alluvium and bedrock.

The screening criteria are presented in several references, as noted below:

- The Final (Approved) Risk-Based Evaluation Procedures Manual, Module III, Development of Sitewide RBCs; Fort Carson, Colorado (Earth Tech 2003a) summarizes the RBCs for organic and inorganic analytes. RBCs are defined as health-protective screening criteria used to screen constituent concentrations for the protection of human receptors. The RBCs are estimated to reflect potential carcinogenic risk or noncarcinogenic effects from potential exposure to a constituent through a specific combination of pathway, medium, and land use.
- The Final Risk-Based Evaluation Procedures Manual, Module IV, Development of Groundwater Protection Levels; Fort Carson, Colorado (Earth Tech 2003b) summarizes the GPLs for organic and inorganic analytes. GPLs are defined as the maximum concentration of a constituent in soil that, if leached to groundwater, would not result in an exceedance of a regulatory or site-specific groundwater quality criterion.
- The Final Risk-Based Procedures Evaluation Manual, Module I, Sitewide Background Data Set for Soil; Fort Carson, Colorado (Earth Tech 2004a) summarizes the background concentrations for inorganic analytes. Fort Carson is predominantly underlain by

Quaternary (Piney Creek and Post-Piney Creek) alluvium and Pierre Shale. Module I generates upper tolerance limits (UTLs) for 23 inorganics in both alluvium (UTL-A) and Pierre Shale (ULT-P) for screening criteria.

4.7.2 Groundwater Results

Groundwater samples were collected during several sampling events from existing monitoring wells and one time from the RFI wells installed in July 2004 (LF2MW01 through LF2MW07) and December 2004 (LF2MW08). The groundwater samples collected in August/September of 2004 and January of 2005 constitute one sampling event. The results from this sampling event are discussed in this section as they relate to initial results, which have been discussed in detail by Earth Tech (2001 and 2004).

The monitoring wells were developed in accordance with section 2.4.3 of the FLPM. The monitoring wells were sampled and field measurements collected for pH, specific conductance, dissolved oxygen, ORP, temperature, and turbidity. Field parameter results fell within normal ranges for groundwater characteristics associated with the Fort Carson area. Analytical results for groundwater samples identified the presence of both organic and inorganic constituents, some at concentrations above their respective screening criteria. The results are summarized in Appendix D (Tables D-1 and D-2). Figures 4-4, 4-5, and 4-6 present all (1994-1995 and 2004-2005) RFI sample detections of organic constituents, nitrate, and selenium, respectively. Many wells that are associated with adjacent SWMUs are identified on these figures because certain constituent detections in these wells are pertinent to determining if the detections relate to Landfill 2 or occur regionally. These constituent detections are discussed further below.

Groundwater sample results for VOCs, SVOCs, metals, explosives, pesticides, PCBs, dioxins, furans, and nitrate were compared to the screening criteria to identify those locations where concentrations exceed screening criteria. Inorganic constituents were detected in Landfill 2 groundwater samples at concentrations exceeding screening criteria. These constituents include aluminum, cadmium, calcium, chloride, cyanide, fluoride, iron, magnesium, manganese, nickel, nitrate, orthophosphate, potassium, selenium, silica, sodium, sulfate, thallium, TDS, and TOC. Based on historical groundwater sampling results, an August 25, 2003 letter from CDPHE to the Director of Environmental Compliance and Management at Fort Carson removed aluminum, calcium, chloride, iron, magnesium, manganese, potassium, sodium, sulfate, and tin as contaminants of concern at Fort Carson. A copy of this letter is found in Appendix B. The few detections above screening criteria for cadmium, cyanide, nickel, and thallium were random detections with no apparent trends. Based on the 2004 sample results, there were no metals identified above their respective screening criteria.

Based on a review of Table 4-4, which presents the RFI organic results, there were no detected concentrations of explosives, pesticides, PCBs, dioxins, and furans above their respective screening criteria. One SVOC, bis(2-ethylhexyl)phthalate, was detected above the screening criteria in several wells, but is considered a common laboratory contaminant.

Figure 4-4 presents the initial and supplemental VOC and SVOC detections in groundwater at monitoring wells in, adjacent to, cross gradient to, and downgradient of Landfill 2. The VOCs identified as contaminants of concern are 1,2-dichloroethane (1,2-DCA); 1,2-dichloropropane (1,2-DCP); benzene; methylene chloride (MC), and vinyl chloride (VC). These VOCs were reported at concentrations above the CGWS in at least one well.

VC was detected in two direct-push wells (LF2DPW6 and LF2DPW7) within the landfill in 1996. These were the only two detections above screening criteria for VC. Contaminants of concern 1,2-DCA and 1,2-DCP were detected above their respective screening criteria at well FCMW76 during several sampling events. 1,2-DCA was also detected slightly above screening criteria in monitoring well FCMW79 in 1997; the well has since been destroyed. MC was also detected above screening criteria in monitoring well FCMW79 in 1997.

Historically, benzene is has only been observed at concentrations above the CGWS in well 2492MW3, which is potentially downgradient of Landfill 2, but more likely is cross gradient. The average historic benzene concentration in this well is 99 μg/L. The results of the 2004 sampling event indicate that benzene is non detect at two upgradient locations (LF2DP17 and LF2DP18), four locations at the downgradient perimeter of Landfill 2 (LF2MW03, LF2MW05, LF2MW06, and LF2MW07), and FCMW74, located approximately 350 feet downgradient of LF2MW05. Therefore, this constituent is currently not considered a contaminant of concern for Landfill 2.

The preliminary RFI results also identified selenium and nitrate as contaminants of concern. Selenium was found at concentrations above the background concentration of 0.27 mg/L at numerous cross gradient and downgradient wells in the vicinity of Landfill 2. Nitrate concentrations above the CGWS (10 mg/L) were found in samples from many wells cross gradient and downgradient of Landfill 2.

Figure 4-5 shows initial nitrate concentration data for monitoring wells in the vicinity of Landfill 2, along with the supplemental Landfill 2 RFI nitrate results. Table 4-5 presents the nitrate detections. There are no historic nitrate concentrations from groundwater monitoring locations inside the landfill boundary that are greater than the CGWS for nitrate. The highest nitrate concentrations are found in monitoring wells FCMW100 (historic average 1585 mg/L), FCMW100A (historic average 835 mg/L), and FCMW202 (historic average 1150 mg/L), which are approximately 1,500 feet west of and cross gradient to the landfill. Well 2492MW3 (discussed above with regard to benzene), has an average historic nitrate concentration of 432 mg/L. Other wells that are located south (downgradient) of the southern apex of the landfill have historic nitrate results greater than the CGWS - from north to south, wells FCMW74, FCMW73, FCMW72, and the southeast to northwest trending line of wells encompassing wells FCMW61 through FCMW68. The historic nitrate concentrations in groundwater for these wells range from 12.9 to 210 mg/L and are greater than the CGWS.

The 2004 sampling event results confirm that wells listed above, which were sampled during this event, had nitrate concentrations well above the CGWS. In addition, monitoring well LF2MW03, located at the southwest corner of the landfill perimeter, had a nitrate concentration of 460 mg/L. On the eastern and southeastern perimeter of the landfill, monitoring wells LF2MW05, LF2MW06, LF2MW07, and LF2MW08 had nitrate concentrations of 0.1, 9.4, 6.1, and 9.6 mg/L, respectively; all below the CGWS. These results are summarized in the following table. Additional 2004 – 2005 nitrate results and found on Figure 4-5.

Well	2004 – 2005 Nitrate Results (mg/L)
LF2MW03	460
LF2MW05	0.1
LF2MW06	9.4
LF2MW07	6.1
LF2MW08	9.6

The analytical results show nitrate concentrations at and downgradient of Landfill 2 may result from the breakdown of sewage treatment plant sludge and other organic waste (mess hall waste) that was placed in Landfill 2. The nitrate concentration at the landfill is probably not related to the former Open Burn/Open Detonation area (SWMU 31) located approximately 400 feet southwest of Landfill 2. If there were saturated flow conditions across the site, this location would potentially be cross gradient to Landfill 2. Nitrate concentrations observed in groundwater farther downgradient of Landfill 2 and at other SWMUs located cross gradient to Landfill 2 support the presence of nitrate sources other than Landfill 2, such as naturally-occurring sources.

Figure 4-6 shows the initial concentration data for selenium at monitoring wells in the vicinity of Landfill 2, along with the supplemental Landfill 2 RFI selenium results. Table 4-6 presents the RFI selenium detections. There are no historic data for selenium from groundwater monitoring wells inside the landfill boundary that are greater than the background concentration for selenium. The highest selenium concentrations are found in the four monitoring wells with the highest nitrate concentrations; FCMW100 (historic average 4.0 mg/L), FCMW100A (historic average 2.5 mg/L), and FCMW202 (historic average 1.4 mg/L), which are approximately 1,500 feet west of and cross gradient to the landfill. Well 2492MW3 has an average historic selenium concentration of 0.94 mg/L. Other wells that are located due south (downgradient) of the southern apex of the landfill have historic selenium results that are non detect or below the background concentration except for FCMW 61, which has an average historic selenium concentration of 0.29 mg/L (discounting one non-detect value).

During the 2004 sampling event only five wells were sampled for selenium. Monitoring wells LF2MW05, LF2MW06, LF2MW07, and FCMW74 had selenium results below the background concentration. Monitoring well FCMW101, located approximately 2,000 feet west of the landfill, had a selenium concentration of 1.2 mg/L.

4.7.3 Sediment Results

Detections of organic and inorganic constituents in sediment samples collected at Landfill 2 are summarized in Appendix D (Table D-2). Metals were detected at concentrations above UTLs at locations LF2SD1 (arsenic), LF2SD3 (cadmium and chromium), and LF2SD4 (arsenic, cadmium, chromium, and lead). No other constituents were detected in sediment samples at concentrations greater than screening criteria. A chlorinated herbicide, 2-methyl-4-chlorophenoxyacetic acid (MCPA), and toluene were detected in sediment sample LF2SD1. MCPA was also detected in sediment sample LF2SD2, along with acetone and di-n-butyl phthalate. Very low concentrations (i.e., below laboratory reporting limits [RLs]) of several other organic compounds, including several polynuclear aromatic hydrocarbons (PAHs), were detected in the four sediment samples.

4.7.4 Soil Gas Results

The 1995 soil gas survey results indicated low methane concentrations in localized areas of Landfill 2, as shown in Figure 4-7. Concentrations of total organic vapors and hydrogen sulfide were below background levels. During the course of the soil gas survey, field personnel did not observe odors typically associated with landfill gas. In addition, pressure measurements collected during the survey indicated that there were no positive pressures at any sampling point. Methane was detected at 13 of the 105 survey locations; therefore, methane gas does not appear to be a problem at the landfill. The 14 geotechnical borings did not encounter large amounts of organic waste, which typically produce methane upon breakdown, but did encounter large amounts of soil mixed with primarily inert waste such as glass, wood, metal, plastic, brick, concrete, and paper.

Four soil gas samples were analyzed in 2004. As with the 1995 results, the sample results indicated low methane concentrations. Table 4-7 summarizes the 2004 soil gas data. Appendix C contains the Landfill Gas Probe Monitoring Form.

The soil gas samples were analyzed in the field using a PID to detect VOCs, and a multi-gas meter was used to measure hydrogen sulfide, oxygen, carbon dioxide, and the lower explosive limit (LEL). The measured concentrations were within safety limits and required no further confirmatory analysis.

4.7.5 Source Water Results

Source water samples collected for metals analyses, with the exception of the samples collected in February 1998 and April 1999, were filtered with a pressurized disposable bailer, which had special fittings that allowed a pump to be attached to the bailer to pressurize the water and force it through a 0.45-micron filter.

VOCs detected in source water samples include bromodichloromethane, bromomethane, chloroform, dibromochloromethane, methylene chloride, carbon disulfide, 2-butanone, and acetone. Bromodichloromethane and chloroform are trihalomethane compounds commonly associated with water treated by chlorination. Methylene chloride and acetone are considered common laboratory contaminants. These samples also contained several metals, the concentrations of which did not exceed any drinking water standard. Additional inorganic results were also obtained, including TOC, alkalinity, anions, nitrate, and TDS. Detectable nitrate concentrations ranged from 0.12 mg/L to 0.19 mg/L, which is well below the drinking water standard of 10 mg/L. TDS concentrations ranged from 42.0 mg/L to 107.0 mg/L.

The source water results indicate that the water used at Fort Carson contains low levels of trihalomethanes and metals. Comparison to the investigation groundwater samples collected during the same time as these samples indicates that the constituents present in the source water supply did not impact the investigation results.

The nature and extent of contamination present in sediment and groundwater has been defined, based on available data, through the RFI conducted at Landfill 2, and are discussed below.

5.1 EXTENT OF WASTE

During the excavation of the geotechnical trenches, the debris and native soil contact was identified (Figure 3-1). Topographic conditions guided the trench placement and aided in delineating the extent of landfill waste. The RFI activities implemented at Landfill 2 established the lateral extent of disposal activities. The lateral extent of waste subsequent to the 1997 – 1998 waste consolidation activities is also found on Figure 3-1. The landfill was determined to be about 73 acres in size. The vertical extent of impact is defined by shallow bedrock depths throughout the site to a maximum of 17 feet. Consequently, no further definition of waste extent is required.

5.2 SOIL GAS

Methane was detected at only 13 of 105 survey locations during 1995, as shown on Figure 4-7. The four soil gas samples analyzed in 2004 had low methane concentrations. Concentrations of total organic vapors and hydrogen sulfide were below background levels. These gases do not appear to be a problem at Landfill 2.

Soils at Landfill 3 were not characterized as part of this RFI because Pierre Shale bedrock underlies the site. Total organic vapors observed at Landfill 2 were below background levels and, because cover materials exhibit a high runoff coefficient, percolation, and transport of inorganic constituents to the Pierre Shale bedrock is unlikely.

5.3 SEDIMENT

Four sediment samples were collected during 1996. Organic analytes detected in these samples were all below screening criteria levels (Table D-2). Sample locations LF2SD3 and LF2SD4, located downgradient of the landfill, had organic and inorganic contaminants detected at concentrations below the screening criteria. Some metals were confirmed at concentrations exceeding the upper tolerance limit for alluvium (UTL-A) screening criteria. Metals were detected at concentrations above screening criteria at locations LF2SD1 (arsenic and manganese), LF2SD3 (cadmium and chromium), and LF2SD4 (arsenic, cadmium, chromium, and lead). No other constituents were detected in sediment samples at concentrations greater than screening criteria.

5.4 GROUNDWATER

Groundwater occurrence at Landfill 2 has been observed to be isolated and generally confined to subtle channels etched into the Pierre Shale bedrock. The nature of contamination potentially associated with Landfill 2 groundwater is discussed below.

5.4.1 Organic Detections

Organic constituents were detected in the groundwater samples collected from monitoring wells downgradient of Landfill 2. Bis(2-ethylhexyl)phthalate; benzene; 1,2-DCA; 1,2-DCP; MC, and VC concentrations exceeded their respective screening criterion. VC and MC are the only VOCs detected at concentrations above their screening criteria within the landfill boundary. 1,2-DCA and 1,2-DCP were detected at concentrations above their respective screening criteria only at well FCMW76, formerly located at the southern landfill boundary. Bis(2-ethylhexyl)phthalate and MC are known to be common laboratory artifacts. The most impacted well in the vicinity of Landfill 2 is 2494MW3, which has historic concentrations that exceed its screening criteria for benzene, nitrate, and selenium. This well is not hydraulically connected to Landfill 2.

5.4.2 Inorganic Detections

Inorganic constituents were also detected in the groundwater samples collected from monitoring wells downgradient of Landfill 2. The inorganic compounds detected at concentrations above screening criteria (including metals and nitrate) are observed at locations downgradient of and cross gradient to the landfill. With the exception of selenium and nitrate, these occurrences are isolated and random.

It has been hypothesized that selenium is oxidized and therefore, mobilized by nitrate in irrigated shale terrains in Western Colorado. Preliminary analysis shows that trends in selenium concentrations match those of nitrate (abstract of Pottorff et al, 2004)

Nitrate was identified as a contaminant of concern because the documentation of wastes disposed in Landfill 2 included sewage sludge from the site sewage treatment plant and mess hall wastes, probably organic in nature. The exact location of the disposed sludge within the landfill is not known. A note in the remarks column of the August 25, 2004, Water Level Data Summary field form states that a water level could not be obtained from monitoring well FCMW77 because the well is “in the middle of a bed of biosolids”. This is the only documented reference to the placement of sewage sludge at Landfill 2. Well FCMW77, although not upgradient of the highest nitrate concentrations (wells FCMW100, FCMW100A, FCMW202, and 2492MW3; all cross gradient with historic nitrate concentrations ranging from 275 to 1670 mg/L), is upgradient of many wells discussed above that have historic nitrate concentrations ranging from 73 to 210 mg/L. The nitrate impacts from Landfill 2, if any, to downgradient wells appear to be less than impacts to other Fort Carson wells that are not hydraulically connected to the landfill.

Sewage treatment plant sludge and mess hall waste disposed in Landfill 2 could be potential sources of the nitrate detected downgradient of Landfill 2. Nitrates have been detected in groundwater at concentrations above the CGWS at multiple Fort Carson locations and it would be inappropriate to attribute the entire elevated nitrate to sludges contained in Landfill 2. In addition, the nitrate concentrations in wells downgradient of Landfill 2 are not as high as the nitrate concentrations in many cross gradient wells. An evaluation is currently being conducted by DECAM to characterize the nature and extent of nitrate and to evaluate potential sources across Fort Carson. Preliminary evaluation results indicate some high nitrate concentrations observed at Fort Carson are probably not generated by potential local sources. Rather, the high nitrate concentrations are potentially from a naturally-occurring source such as the underlying Pierre Shale.

Selenium has been detected in several wells in the Landfill 2 area, and is commonly found in Colorado at concentrations above the CGWS (0.05 mg/L). The background concentration for selenium at Fort Carson is 0.27 mg/L. The highest concentrations have been seen in wells FCMW100, FCMW100A, FCMW101, and FCMW202. These locations are cross gradient to the landfill. Downgradient detections are below the background concentration except for one location (FCMW61). Selenium is a natural component of rocks and minerals and has been shown to be present in concentrations up to 103 ppm in the Pierre Shale (Presser et al. 1990). Selenium can substitute for sulfur in minerals and may be present in finely dispersed pyrite or other minerals. Analyses of over 500 samples collected in South Dakota, primarily from the Pierre Shale and Niobrara Formation (stratigraphically below the Pierre Shale), averaged 5.8 ppm of selenium with a maximum of 113 ppm of selenium (Wilson et al. 1990). According to Howard (1969), the Smoky Hill Member of the Niobrara Formation and the Pierre Shale are the most highly seleniferous of the Upper Cretaceous formations in south-central Colorado. The selenium is attributed to the weathering of selenium-bearing sulfides, particularly pyrite, that occur as minute grains that are disseminated in the shale. Pyrite weathering products include ferric hydroxide and jarosite and may contain selenium in excess of 100 ppm. The Pierre Shale, which underlies most of Fort Carson, is the likely source of the selenium, and potentially, the source of nitrate detected in groundwater at Landfill 2.

In summary, there is the potential for a release of nitrate from Landfill 2, but the nitrate concentrations downgradient of the landfill are less than nitrate concentrations in other areas of Fort Carson. None of the impacted groundwater flows beneath a residential area or is utilized as a drinking water source.

The environmental fate and transport of site-related contaminants, especially those that appear to be widespread, is important in determining the potential for human and ecological exposure. Contaminants may migrate from the Fort Carson Landfill 2 site by several mechanisms. Migration into the air can occur via volatilization or dust generation. Migration into groundwater can occur by percolation of infiltrating precipitation or groundwater flow through waste material or contaminated soil. Soil gas analyses have shown that VOCs are not a problem in the waste/soil mix in the landfill and there is no soil beneath the landfill. Inorganic constituent transport through the waste/soil mix in the landfill is unlikely. Transport to streams in the area can occur via surface water runoff and through groundwater discharge. Sediment analyses have shown that surface water is not a viable contaminant transport pathway. The migration mechanisms for the constituents detected at the site are discussed in detail below. The general persistence of the contaminants in the environment is also discussed below.

Surface soils in the vicinity of the landfill have a high potential for runoff and, therefore, a low potential for infiltration. In addition, there does not appear to be a continuous saturated thickness beneath and adjacent to the landfill; therefore, a great overall flux of groundwater is not emanating from the landfill. As the hydrogeologic conceptual model indicates, groundwater emanates from the landfill in isolated, generally north-south/southeast trending channels etched into the Pierre Shale bedrock surface. The combination of these two aspects of the hydrologic regime indicate that there is a low potential for contaminant migration from surface soil to subsurface soil, from subsurface soil into groundwater, and from isolated landfill groundwater to downgradient groundwater. The net effect is that, except for locations where the groundwater collects and drains from the landfill area via bedrock channels (for instance along the southeastern landfill boundary) there is not a large flux of groundwater exiting the landfill.

6.1 ORGANIC CONTAMINANT FATE AND TRANSPORT

VOC concentrations in groundwater at Landfill 2 have been detected above screening criteria, including 1,2-DCA; 1,2-DCP; VC; MC; benzene; and bis(2-ethylhexyl)phthalate. A number of other VOCs were detected at concentrations below screening criteria. It is unknown whether chlorinated constituents were used at Fort Carson as primary solvents in machining and degreasing/cleaning operations. Reductive dechlorination of tetrachloroethene (PCE), trichloroethene (TCE), and carbon tetrachloride (CT) may be the likely source of VC and MC as daughter products, although PCE, TCE, and CT are not detected in Landfill 2 groundwater samples above their respective screening criteria.

The physical and chemical properties of VOCs govern their transport, fate, and toxicity in the subsurface environment. The number of substituted chlorine atoms on the chlorinated species directly affects their physical and chemical behavior. As the number of substituted chlorine atoms increases, molecular weight and density generally increase and vapor pressure and aqueous solubility generally decrease. Also, as solubility decreases, sorption increases.

Chlorinated hydrocarbons and petroleum hydrocarbons released to the subsurface as free-phase liquids are referred to as non-aqueous phase liquids (NAPLs) because of their limited solubility in water. Dense non-aqueous phase liquids (DNAPLs) are denser than water and, when released to the environment, tend to sink through both the unsaturated (vadose) zone and saturated permeable soils until they reach the top of a confining layer or settle within a bedrock fracture. Light non-aqueous phase liquids (LNAPLs) are less dense than water and, when released to the environment, tend to sink through the vadose zone and float on groundwater in the saturated zone. Coverillary forces can trap NAPLs in porous media above the water table.

VOCs in the subsurface can remain as a NAPL, adsorb to soil, dissolve in groundwater, or volatilize to soil gas to the extent allowed by the physical and chemical properties of the individual VOC and the subsurface environment. Subsurface VOCs usually attempt to equilibrate with the subsurface environment via partitioning. Partition coefficients, which are related to the hydrophobicity and aqueous solubility of a VOC, define the extent to which a VOC will partition as NAPL, adsorb to soil, and dissolve in groundwater. The vapor pressure of a VOC defines the extent to which it will partition among NAPL, the soil, and soil gas.

VOCs dissolved in groundwater may also partition between dissolved and vapor phases as determined by their Henry's Law constant. However, once VOCs are dissolved in groundwater, their high volatility is of little assistance in their removal from the subsurface as transport across the coverillary fringe can be exceedingly slow (McCarthy and Johnson, 1992). This process is distinct from attenuation via ET. VOC volatility is very beneficial where groundwater discharges to flowing surface water, and volatilization can occur.

VOCs migrate in the subsurface as non-aqueous, aqueous, and vapor phases by both active and passive processes. Active migration, such as advection and dispersion, transport VOCs along with groundwater or soil gas. Passive migration, such as diffusion, is the result of concentration gradients, which cause the VOCs to seek phase and concentration equilibrium with their surrounding environment. In groundwater, the transport effects of diffusion are negligible. The extent of subsurface migration is a function of the volume released, area and duration of the release, and physical and chemical properties of the VOC and the subsurface environment.

Infiltrating rainfall and seasonal water table fluctuations flowing through residual NAPL zones within the unsaturated zone may also provide a persistent source of VOCs into groundwater. Most of the current VOC distribution throughout and downgradient of Landfill 2 is probably caused by advection, where dissolved phase contaminants simply move in groundwater from source areas to downgradient areas. As a result, VOC contaminant distributions should generally reflect groundwater flow directions. Unfortunately, at Landfill 2, exact flow directions cannot be calculated because of the lack of an areally extensive water table, but are hypothesized to be to the south and southeast.

Increased groundwater flow velocities in the unconsolidated alluvial or colluvial material may cause faster advective transport of VOCs relative to the weathered Pierre Shale bedrock. However, as contaminants move from upper landfill areas downgradient towards stream areas, climate variability can cause groundwater levels to fluctuate across the alluvium/weathered bedrock contact, which in turn causes increased mixing of the VOCs across the various geologic units that comprise the saturated areas at the site. This can result in relatively small amounts of groundwater impacted by VOCs discharging into seeps or streams downgradient of the landfill.

VOCs can also be adsorbed onto the porous medium through which they travel. This decreases groundwater concentrations, although over time, adsorption rates may decline and thus this process may only retard the transport of high VOC concentrations from constant sources. In general, diffusive processes are typically small, but their effects can become large relative to dispersive effects in lower groundwater velocity areas, like weathered bedrock claystones and shales.

The current extent of VOCs at Fort Carson Landfill 2 is largely confined to the limited groundwater occurrence in the area. This suggests that VOC transport is relatively slow and may have reached a steady-state condition. The apparently limited migration of VOCs in groundwater at Landfill 2 is likely a combination of several mechanisms, including hydraulic properties, climatic influences, source concentration, groundwater flux, biodegradation, and sorption.

6.2 INORGANIC CONTAMINANT FATE AND TRANSPORT

The following sections discuss the environmental fate and transport of nitrate and metals, including selenium.

6.2.1 Nitrate Fate and Transport

Nitrate (NO_3^-) and nitrite (NO_2^-) are naturally occurring inorganic anions that exist in soil and groundwater and that are part of the nitrogen cycle. The atmosphere, which contains 78 percent nitrogen, is the principal nitrogen source. Other common forms of dissolved nitrogen in groundwater may include ammonium (NH_4^+), ammonia (NH_3), nitrogen (N_2), nitrous oxide (N_2O), and organic nitrogen, depending on redox conditions. Potential nitrate sources at Fort Carson include animal or human waste, industrial waste, nitrogen-containing fertilizers, explosives used in conjunction with military training exercises, and the Pierre Shale. The Pierre Shale underlies much of Fort Carson, including the Landfill 2 area.

Naturally occurring nitrate in soil, surface water, and groundwater result from the decomposition by microorganisms of organic nitrogenous material, such as the protein in plants, animals, and animal excreta. The ammonium ion formed is oxidized to nitrite and nitrate under aerobic conditions. Denitrification of nitrate and ammonia to nitrous oxide and elemental nitrogen can occur by bacterial action under anaerobic conditions (Fetter 1980). The natural occurrence of nitrate and nitrite in the environment is a consequence of the nitrogen cycle. However, nitrite is short-lived in groundwater and generally only found in very low concentrations because most environments are oxic (i.e., well oxygenated), which favors the nitrate anion.

Fort Carson groundwater and surface water are generally oxic and nitrite is easily oxidized to nitrate; therefore, nitrate is the predominant dissolved nitrogen species in site water. However, localized areas of other dissolved nitrogen species may occur where the groundwater is anoxic and reducing conditions exist, for example beneath areas of Landfill 2 where sewage sludge and other organic wastes were disposed.

Nitrate concentrations in groundwater are generally not limited by solubility constraints (Freeze and Cherry 1979). As a result, nitrate in Fort Carson soil and groundwater is likely to be highly soluble and very mobile within the aqueous phase. From a transport perspective, nitrate is considered a conservative constituent, like chloride, because it is not readily sorbed (i.e., retarded) and generally migrates at the same rate as groundwater flow. However, in heavily vegetated areas, nitrate uptake by plants may influence its overall transport behavior (Drever 1988).

6.2.2 Metals Fate and Transport

It is often assumed that metals measured at a site are contaminants, when in reality; high concentrations of many metals are native to specific locations.

In soil and sediment, metal constituents are dissolved in the soil solution, adsorbed or (ion) exchanged on inorganic soil constituents, complexed with insoluble soil organic matter, or precipitated as pure or mixed solids. Metals in the soil solution are subject to movement with soil water and may be transported through the vadose zone to groundwater, taken up by plants and aquatic organisms, or volatilized. Unlike organic constituents, metals cannot be degraded, but some metals, such as arsenic, chromium, and mercury can be transformed among various oxidation states, altering their mobility and toxicity. In addition, metals participate in chemical reactions within the soil solid phase. Metal immobilization by adsorption, ion exchange, complexation, and precipitation can prevent the movement of metals to groundwater. Soil condition changes, such as degradation of organic matrices and changes in pH, redox potential, or soil solution composition because of various remediation schemes or natural weathering processes, may also change metal mobility (EPA 1995).

Concentrations of seven metal compounds exceeded the UTLs in sediment. Concentrations of two regulated metal compounds slightly exceeded their respective screening criterion in groundwater. Metal constituents detected in groundwater were similar to those detected in sediment. This suggests that these metal compounds are most likely naturally occurring and not a direct result of past activities at Landfill 2.

6.2.3 Selenium Fate and Transport

Selenium mobility is controlled by geochemical conditions. Selenium can occur in four valence states, listed here from most reduced (most electrons) to most oxidized (fewest electrons): selenide (-2), elemental selenium (0), selenite (+4), and selenate (+6). Selenium is closely associated with iron; selenide substitutes for sulfur in pyrite and other sulfide minerals. Selenite adsorbs strongly to ferric hydroxide and less strongly to manganese dioxide. Selenite adsorption increases as pH decreases as long as the adsorbing mineral is stable. Selenate does not adsorb as strongly to ferric hydroxides as does selenite; selenate does not adsorb to manganese dioxide. (Howard 1977; Balistrieri and Chao 1990).

Bacteria have been found to be important in selenium transformations. Bacterial reduction of selenate results in selenite. This reductive activity is considered to be widespread in sediments and could account for removal of selenium from surface water that is infiltrating to groundwater (Weres et al. 1990). However, in the presence of nitrate, selenium removal is not as pronounced. Nitrate appears to inhibit the reduction of selenate to selenite, resulting in the transport of this more mobile form of selenium (Weres et al. 1990). Nitrate may need to be absent prior to selenate reduction to selenite.

The sewage sludge disposed in Landfill 2 may be responsible for creating reducing conditions in groundwater beneath the landfill. Reducing conditions tend to immobilize selenium as selenide or elemental selenium, thus restricting their mobility in groundwater.

The Landfill 2 RFI objectives were to:

- Determine the landfill waste extent
- Determine the cover material thickness and characteristics
- Determine if adjacent surface water and sediments have been adversely affected by the landfill
- Determine if shallow groundwater is present below Landfill 2 and if groundwater beneath and downgradient of the landfill has been adversely affected by the landfill
- Determine the nature and extent of groundwater contamination, if present
- Determine the fate and transport of contamination, if present
- Collect data for future evaluation of human and ecological risk

Based on the results of this RFI, the project objectives have been accomplished. In addition, the fate and transport of organic and inorganic constituents in groundwater has been addressed.

Field mapping activities indicate that the Landfill 2 waste extent is understood, and is expressed by topographic changes at the site. The western and southern waste extents are delineated by an apparent slope transition. Construction and demolition debris, including brick, concrete, and empty barrels, were identified on the face of the ridge along the north side of the landfill. Field mapping along the east side of the landfill identified waste east of the existing concrete channel. Waste material was also encountered in the geotechnical borings and landfill trenches and was comprised mostly of glass, metal, wood, plastic, brick, concrete, and paper mixed with daily soil cover. The geophysical survey was not able to differentiate between waste and native soil because of the large amount of soil mixed with the waste, as observed in the geotechnical borings and trenches.

During the geotechnical boring and trenching activities, field observations identified the presence of an existing landfill cover over the greater portion, approximately 50 acres, of Landfill 2; however, surficial wastes were identified along the northern portion of the landfill. The existing cover materials, ranging in thickness from 4 to 15 feet, were comprised of reworked alluvium and Pierre Shale.

Low methane concentrations were detected in localized areas of the landfill. Total organic vapor concentrations measured in the soil gas samples were below background levels. The geotechnical borings and trenches did not encounter potentially methane producing organic waste, but generally inorganic waste mixed with large amounts of soil.

Organic constituents were detected in Landfill 2 groundwater samples at concentrations exceeding screening criteria. These constituents include VC; pentachlorophenol; 1,2-DCA; 1,2-DCP; MC; and bis(2-ethylhexyl)phthalate. All of these detections occurred either one time or at isolated and/or random locations. Other VOCs were detected at concentrations below screening criteria. The groundwater sampling results indicate that the VOCs detected at concentrations above and below screening criteria were present primarily within the landfill boundary. It may be that the VOC-contaminated groundwater within the landfill exists because of isolated point sources, but there are insufficient sampling locations and results to determine this.

Regulated inorganic constituents were also detected in Landfill 2 groundwater samples at concentrations exceeding screening criteria. These constituents include cadmium, cyanide, fluoride, nitrate, orthophosphate, selenium, silica, thallium, TDS, and TOC. The cadmium, cyanide, and thallium detections were isolated. Nitrate and selenium were detected at elevated concentrations primarily in downgradient and cross gradient monitoring wells, generally not in monitoring wells within the landfill boundary.

Vertical and lateral transport of constituents through the soil and groundwater, respectively, and airborne transport are all concerns associated with a landfill site. Due to physical site conditions, few concentration detections, and the lack of groundwater, specific pathways cannot be identified. The clayey nature of landfill cover materials, and the high potential for precipitation runoff, allow for little infiltration into the landfill and, therefore, little transport of constituents to the surface of the Pierre Shale. Shallow bedrock conditions and the absence of groundwater throughout the majority of the site have resulted in limited transport of the defected constituents.

Based on the RFI results, the only constituent identified that potentially has had an impact on groundwater downgradient of Landfill 2 is nitrate, although the concentrations of nitrate at the southeast boundary, where groundwater from Landfill 2 may collect, indicate there are generally no nitrate impacts to groundwater at the landfill. RFI results indicate that no significant impacts to the surrounding environment have resulted from the past activities at Landfill 2.

As discussed above, the geotechnical borings and trenches identified the presence of an existing landfill cover over the approximately 50-acre central portion of Landfill 2. This cover may not conform to current regulations but, as discussed above, is promoting runoff and limiting infiltration into the landfill. The existing cover appears to be serving its purpose and meeting the regulatory considerations listed below:

- Provide long-term control of migration of liquid through the closed landfill
- Function with low maintenance
- Promote drainage and controls erosion or abrasion of the cover
- Accommodate subsidence, so that the cover integrity is maintained

A final landfill cover may need to be installed at Landfill 2 based on requirements set forth by CDPHE and based on the results of a CMS.

The long-term monitoring program at Landfill 2 should include monitoring of perimeter monitoring wells and soil gas probes to ensure that migration of hazardous constituents from the landfill is not occurring.

American Society for Testing and Materials (ASTM). 1994a. Designation D2487-92 *Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System).*

ASTM. 1994b. Designation D2488-90 *Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)*.

Balistrieri, L.S., and T.T. Chao. 1990. "Adsorption of selenium by amorphous iron oxyhydroxide and manganese dioxide", in *Geochimica et Cosmochimica Acta*, Vol. 45, pp. 739-751.

Code of Colorado Regulations (CCR). 2003. Hazardous Materials and Solid Waste Regulations 1007, Part 264, Appendix IX, *Groundwater Monitoring List*. April.

CCR. 2005. Title 5, Chapter 1002, Article 8, Section 3.11.0, Regulation 41. *Basic Standards for Groundwater*. March.

Colorado Department of Public Health and Environment (CDPHE). 1995. RCRA Hazardous Waste Part B Permit No. CO-95-09-29-03. Effective October 29.

Earth Tech Environment and Infrastructure, Inc. (Earth Tech). 2000. *Final RCRA Facility Investigation Report, Grit/Oil Pit (FTC-020/SWMU 13), Fort Carson, Colorado.* May.

Earth Tech. 2001. *Draft RCRA Facility Investigation Report, Landfill 2 (FTC-006/SWMU 2), Fort Carson, Colorado.* April.

Earth Tech. 2003a. *Risk-Based Evaluation Procedures Manual, Module III, Development of Sitewide RBCs, Fort Carson, Colorado.* Final (Approved). March.

Earth Tech. 2003b. *Final Risk-Based Evaluation Procedures Manual, Module IV, Development of Groundwater Protection Levels, Fort Carson, Colorado.* October 10, 2003.

Earth Tech. 2003c. *Final Risk-Based Procedures Evaluation Manual, Module II, Sitewide Background Data Set for Soil, Fort Carson, Colorado.* October 17, 2003.

Earth Tech. 2004a. *Final Risk-Based Procedures Evaluation Manual, Module I, Sitewide Background Data Set for Soil, Fort Carson, Colorado.* April.

Earth Tech. 2004b. *Final RCRA Facility Investigation Work Plan Addendum, Landfill 2 (FTC-006/SWMU 2), Fort Carson, Colorado.* May.

Environmental Protection Agency (EPA). 1995. *Contaminants and Remedial Options at Selected Metal-Contaminated Sites.*

EPA. 2002. *Drinking Water Regulations and Health Standards.*

Drever, J.I. 1988. “The Geochemistry of Natural Waters.” Prentice-Hall, Inc. Englewood Cliffs, NJ.

Fetter, C.W., Jr. 1980. “Applied Hydrogeology.” Charles E. Merrill Publishing Company, Columbus, OH.

Freeze, R. Allen and John A. Cherry. 1979. “Groundwater.” Prentice-Hall, Inc. Englewood Cliffs, NJ.

Howard, J.H., III. 1969. Selenium in the Upper Cretaceous Niobrara Formation and Pierre Shale of South-Central Colorado. Geological Society of American Special Paper 121, p.606.

Howard, J.H., III. 1977. “Geochemistry of selenium: formation of ferroselenite and selenium behavior in the vicinity of oxidizing sulfide and uranium deposits”, in *Geochimica et Cosmochimica Acta,* Vol. 41, pp. 1665-1678.

HQ Fort Carson. 1988. Part B Permit Application for Miscellaneous Hazardous Waste Management Units. *Open Burning/Open Detonation Units, Fort Carson, Colorado.* October; 1988.

Pottorff et al, 2004. Case study of Selenium Mobilization from Mancos Shale: Relationship to Nitrate Contamination (abstract).

Presser, T.S., W.C. Swain, T.T. Tidball, and R.C. Severson. 1990. *Geologic Sources, Mobilization, and Transport of Selenium from the California Coast Ranges to the Western San Joaquin Valley: A Reconnaissance Study.* U.S. Geological Survey Water-Resources Investigations Report 90-4070. Menlo Park.

Rust Environment & Infrastructure (Rust). 1994. *Draft Sampling and Analysis Plan for Remedial Design, Landfills 2 (FTC-006), 5 (FTC-009), and 6 (FTC-010), and Vapor Degreasing/Spray Jet Washers (FTC-058).* September.

Rust. 1995a. *Revised Final Sampling and Analysis Plan Modification Letter for Remedial Design, Landfills 2 (FTC-006), 5 (FTC-009), and 6 (FTC-010), and Vapor Degreasing/Spray Jet Washers (FTC-058).* April.

Rust. 1995b. *Landfill 2 Analytical Data Package, HydroLogic Laboratories, Inc.* July.

Rust. 1995c. *Revised Conceptual (30%) Design/Engineering Design Analysis for Landfill 2 (FTC-006).* November.

Rust. 1995d. *Revised Final Sampling and Analysis Plan for Remedial Design, Landfills 2 (FTC-006), 5 (FTC-009), and 6 (FTC-010), and Vapor Degreasing/Spray Jet Washers (FTC-058).* December.

Rust. 1996a. *Letter Work Plan for Surface Water and Sediment Sampling at Landfills 2, 5, and 6.* April.

Rust. 1996b. *Final Design Analysis for Landfill 2.* May.

Rust. 1996c. *Landfill 2 Analytical Data Package, HydroLogic Laboratories and Quanterra Environmental Services.* September.

Rust. 1996d. *Quality Control Summary Report for Landfills 2, 5, and 6 (FTC-006, FTC-009, and FTC-010).* October.

Rust. 1996e. *Draft Final Landfills 2, 5, & 6 Cover Installation Project Work Plan.* December.

Rust. 1997. *Field and Laboratory Procedures Manual, Revision 2, Fort Carson, Colorado.* April.

Rust. 1998a. *Draft Final Gradefill Work Plan, Phase I, Landfill 2 (FTC-006).* January.

Rust. 1998b. "Letter Report, Gas Probe Monitoring Results for Landfills 2, 5, and 6." June.

Rust. 1998c. *Field and Laboratory Procedures Manual, Revision 3, Fort Carson, Colorado.* September.

Science Applications International Corporation (SAIC). 1994. *Final RCRA Facility Assessment for Fort Carson, Colorado Springs, Colorado*. May.

State of Colorado, Office of the State Engineer, State Board of Examiners of Water Well Construction and Pump Installation Contractors. 2000. *Rules and Regulations for Water Well Construction, Pump Installation, and Monitoring and Observation Hole/Well Construction.* June.

Trimble and Machette. 1979. Geologic Map of the Colorado Springs-Castle Rock Area, Front Range Urban Corridor, Colorado.

U.S. Army Environmental Hygiene Agency (USAEHA). 1985. *Phase 2 Geohydrologic Study No. 36-26-0392-87, Fort Carson, Colorado.* August.

USAEHA. 1988. *Investigation of Closed Landfills, Fort Carson, Colorado. Ground-Water Quality Study No. 38-26-0897-89.* June and November.

USAEHA. 1992. *Investigation of Ground-Water Quality at Selected Landfills, the Butts Army Airfield, and the Propellant Burning Ground, Fort Carson, Colorado.* Ground-Water Consultation No. 38-26-KM44-92. December.

Weres, O., H.R. Bowman, A. Goldstein, E.C. Smith, L. Tsao, and W. Harnden. 1990. *The effect of nitrate and organic matter upon mobility of selenium in groundwater and in a water treatment process in Water, Air and Soil Pollution,* Vol. 49, pp. 251-272.

Wilson et al. 1990. *Total and Water Extractable Selenium in Soils and Stream Sediments, and Total Selenium in Alfalfa from the Marty II Study Area, South Dakota*. Microform I.

Tables

Figures